

NOVEL GAS BOOSTER SYSTEM

Cross-reference to related patent applications

This application is a continuation-in-part of applicants' copending patent application U.S.S.N. 09/977,002, filed on October 12, 2001, now United States patent 6,688,857, which was a continuation-in-part of copending patent application U.S.S.N. 09/536,332, filed on March 24, 2000, which was a continuation-in-part of U.S.S.N. 09/416,291, filed on October 14, 1999, which was a continuation-in-part of U.S.S.N. 09/396,034, filed on September 15, 1999, which in turn was a continuation-in-part of patent application U.S.S.N. 09/181,307, filed on October 28, 1998.

Field of the invention

A rotary device containing a housing having a curved inner surface with a profile equidistant from a trochoidal curve, an eccentric mounted on a shaft disposed within the housing, a rotor mounted on the eccentric shaft which contains at least three intersecting faces, a partial bore located at the intersection of adjacent faces, and at least three rollers rotatably mounted within the partial bores of the roller. The rotor is comprised of a front face, a back face, a first side, a second side, and a third side. On each front and back face, between adjacent sides, an opening is formed. The openings are not aligned with each other, and the degree of misalignment is in accordance with a specified formula.

Background of the invention

In applicants' United States patent 5,431,551, there is disclosed and claimed a rotary device comprised of a housing comprising a curved inner surface with a profile equidistant from a trochoidal curve, an eccentric mounted on a shaft disposed within said first housing, a first rotor mounted on said eccentric shaft which is comprised of a first side, a second side, and a third side, a first partial bore disposed at the intersection of said first side and said second side, a second partial bore disposed at the intersection of said second side and said third side, a third partial bore disposed at the intersection of said third side and said first side, a first solid roller disposed and rotatably mounted within said first solid bore, a second solid roller disposed and rotatably mounted within said second partial bore, and a third solid roller disposed and rotatably mounted within said third partial bore. The rotor is comprised of a front face, a back face, a first side, a second side, and a third side, wherein a first opening is formed between and communicates between said front face and said first side, a second opening is formed between and communicates between said back face and said first side, wherein each of said first opening and said second opening is substantially equidistant and symmetrical between said first partial bore and said second partial bore, a third opening is formed between and communicates between said front face and said second side, a fourth opening is formed between and communicates between said back face and said second side, wherein each of said third opening and said fourth opening is substantially equidistant and symmetrical between said second partial bore and said third partial bore, a fifth opening is formed between and communicates between said front face and said third side, and a sixth opening is formed between and communicates between said back

face and said third side, wherein each of said fifth opening and said sixth opening is substantially equidistant and symmetrical between said third partial bore and said first partial bore. Each of said first partial bore, said second partial bore, and said third partial bore is comprised of a centerpoint which, as said rotary device rotates, moves along said trochoidal curve. Each of said first opening, said second opening, said third opening, said fourth opening, said fifth opening, and said sixth opening has a substantially U-shaped cross-sectional shape defined by a first linear side, a second linear side, and an arcuate section joining said first linear side and said second linear side, wherein said first linear side and said second linear side are disposed with respect to each other at an angle of less than ninety degrees, and said substantially U-shaped cross-sectional shape has a depth which is at least equal to its width. The diameter of said first solid roller is equal to the diameter of said second solid roller, and the diameter of said second solid roller is equal to the diameter of said third solid roller. The widths of each of said first opening said second opening, said third opening, said fourth opening, said fifth opening, and said sixth opening are substantially the same, and the width of each of said openings is less than the diameter of said first solid roller. Each of said first side, said second side, and said third side has substantially the same geometry and size and is a composite shape comprised of a first section and a second section, wherein said first section has a shape which is different from said second section.

A similar patent, United States patent 6,301,898, issued to applicants' on October 16, 2001.

The entire disclosure of each of United States patent 5,431,551 and 6,301,898 is hereby incorporated by reference into this specification.

It is an object of this invention to provide a improved compression system which utilizes the compressors of such United States patents.

Summary of the invention

In accordance with this invention, there is provided a system for compressing gas comprised of a liquid lubricated rotary positive displacement compressor system. The compressor system contains a rotary positive displacement compressor comprising a housing comprising a curved inner surface with a profile equidistant from a trochoidal curve, an eccentric mounted on a shaft disposed within said housing, a first rotor mounted on said eccentric shaft which is comprised of a first side, a second side, and a third side, a first partial bore disposed at the intersection of said first side and said second side, a second partial bore disposed at the intersection of said second side and said third side, a third partial bore disposed at the intersection of said third side and said first side, a first roller disposed and rotatably mounted within said first partial bore, a second roller disposed and rotatably mounted within said second partial bore, and a third roller disposed and rotatably mounted within said third partial bore. The liquid lubricated rotary positive displacement system also contains (a) a device for separating a mixture of gas and liquid to produce a separated liquid, wherein said means for separating said mixture of gas and liquid is connected to said rotary positive displacement compressor, (b) a device for cooling the separated liquid to produce a cooled separated liquid, and (c) a device for feeding the cooled separated liquid into said rotary positive displacement compressor.

Brief description of the drawings

The claimed invention will be described by reference to the specification and the following drawings, in which:

Figure 1 is a perspective view of one preferred rotary mechanism claimed in United States patent 5,431,551;

Figure 2 is an axial, cross-sectional view of the mechanism of Figure 1;

Figure 3 is a perspective view of the eccentric crank of the mechanism of Figure 1;

Figure 4A is a transverse, cross-sectional view of the eccentric crank of Figure 3;

Figure 5 is a perspective view of the rotor of the device of Figure 1;

Figure 6 is an axial, cross-sectional view of the rotor of Figure 5;

Figure 7 is a transverse, cross-sectional view of the rotor of Figure 5;

Figure 8 is an exploded, perspective view of the device of Figure 1;

Figure 9 is a sectional view of one hollow roller which can be used in the rotary positive displacement device of this invention;

Figure 10 is a sectional view of another hollow roller which can be used in the rotary positive displacement device of this invention;

Figure 11 is a schematic view of a modified rotor which can be used in the positive displacement device of this invention;

Figure 12 is a block diagram of a preferred electrical generation system;

Figure 13 is a block diagram of the gas booster system of Figure 12;

Figure 14 is a schematic representation of an apparatus comprised of a guided rotor device and a reciprocating compressor;

Figure 15 is a schematic representation of another apparatus comprised of a guided rotor device and a reciprocating compressor;

Figure 16 is a schematic representation of another guided rotor apparatus; and

Figure 17 is a schematic representation of yet another guided rotor apparatus;

Figure 18 is a sectional view of a multi-stage guided rotor assembly;

Figure 19 is a sectional view of a guided rotor assembly with its drive motor enclosed within a hermetic system;

Figure 20 is a schematic of one preferred compressor system of the invention;

Figure 21 is a schematic of another preferred compressor system of the invention;

Figure 22 is a schematic representation of compressor assembly compressed of a compressor system, a cooler, and a separator;

Figure 23 is a schematic of another preferred compressor system; and

Figure 24 is a schematic of yet another preferred compressor system.

Description of the preferred embodiments

Figures 1, 2, 3, 4, 4A, 5, 6, 7, and 8 are identical to the Figures 1, 2, 3, 4, 4A, 5, 6, 7, and 8 appearing in United States patent 5,431,551; and they are presented in this case to illustrate the similarities and differences between the rotary positive displacement device of such patent and the rotary positive displacement device of the instant application. The entire disclosure, the drawings, the claims, and the abstract of United States patent 5,431,551 are hereby incorporated by reference into this specification.

Referring to Figures 1 through 8, and to the embodiment depicted therein, it will be noted that rollers 18, 20, 22, and 24 (see Figures 1 and 8) are solid. In the rotary

positive displacement device of the instant invention, however, the rollers used are hollow.

Figure 9 is a sectional view of a hollow roller 100 which may be used to replace the rollers 18, 20, 22, and 24 of the device of Figures 1 through 8. In the preferred embodiment depicted, it will be seen that roller 100 is a hollow cylindrical tube 102 with ends 104 and 106.

Tube 102 may consist of metallic and/or non-metallic material, such as aluminum, bronze, polyethyletherketone, reinforced plastic, and the like. The hollow portion 108 of tube 102 has a diameter 110 which is at least about 50 percent of the outer diameter 112 of tube 102.

The presence of ends 106 and 108 prevents the passage of gas from a low pressure region (not shown) to a high pressure region (not shown). These ends may be attached to tube 102 by conventional means, such as adhesive means, friction means, fasteners, threading, etc.

In the preferred embodiment depicted, the ends 106 and 108 are aligned with the ends 114 and 116 of tube 102. In another embodiment, either or both of such ends 106 and 108 are not so aligned.

In one embodiment, the ends 106 and 108 consist essentially of the same material from which tube 102 is made. In another embodiment, different materials are present in either or both of ends 106 and 108, and tube 102.

In one embodiment, one of ends 106 and/or 108 is more resistant to wear than another one of such ends, and/or is more elastic.

Figure 10 is sectional view of another preferred hollow roller 130, which is comprised of a hollow cylindrical tube 132, end 134, end 136, resilient means 138, and O-rings 140 and 142. In this embodiment, a spring 138 is disposed between and contiguous with ends 134 and 136, urging such ends in the directions of arrows 144 and 146, respectively. It will be appreciated that these spring-loaded ends tend to minimize the clearance between roller 130 and the housing in which it is disposed; and the O-rings 140 and 142 tend to prevent gas and/or liquid from entering the hollow center section 150.

In the preferred embodiment depicted, the ends 144 and 146 are aligned with the ends 152 and 154 of tube 132. In another embodiment, not shown, one or both of ends 144 and/or 146 are not so aligned.

The resilient means 138 may be, e.g., a coil spring, a flat spring, and/or any other suitable resilient biasing means.

Figure 11 is a schematic view of a rotor 200 which may be used in place of the rotor 16 depicted in Figures 1, 5, 6, 7, and 8. Referring to Figure 11, partial bores 202, 204, 206, and 208 are similar in function, to at least some extent, the partial bores 61, 63, 65, and 67 depicted in Figures 5, 6, 7, and 8. Although, in Figure 11, a different partial bore has been depicted for elements 202, 204, 206, and 208, it will be appreciated that this has been done primarily for the sake of simplicity of representation and that, in most instances, each of partial bores 61, 63, 65, and 67 will be substantially identical to each other.

It will also be appreciated that the partial bores 202, 204, 206, and 208 are adapted to be substantially compliant to the forces and loads exerted upon the rollers (not

shown) disposed within said partial bores and, additionally, to exert an outwardly extending force upon each of said rollers (not shown) to reduce the clearances between them and the housing (not shown).

Referring to Figure 11, partial bore 202 is comprised of a ribbon spring 210 removably attached to rotor 16 at points 212 and 214. Because of such attachment, ribbon spring 210 neither rotates nor slips during use. The ribbon spring 210 may be metallic or non-metallic.

In one embodiment, depicted in Figure 11, the ribbon spring 210 extends over an arc greater than 90 degrees, thereby allowing it to accept loads at points which are far from centerline 216.

Partial bore 204 is comprised of a bent spring 220 which is affixed at ends 222 and 224 and provides substantially the same function as ribbon spring 210. However, because bent spring extends over an arc less than 90 degrees, it accepts loads primarily at around centerline 226.

Partial bore 206 is comprised of a cavity 230 in which is disposed bent spring 232 and insert 234 which contains partial bore 206. It will be apparent that the roller disposed within bore 206 (and also within bores 202 and 204) are trapped by the shape of the bore and, thus, in spite of any outwardly extending resilient forces, cannot be forced out of the partial bore. In another embodiment, not shown, the partial bores 202, 204, 206, and 208 do not extend beyond the point that rollers are entrapped, and thus the rollers are free to partially or completely extend beyond the partial bores.

Referring again to Figure 11, it will be seen that partial bore 208 is comprised of a ribbon spring 250 which is similar to ribbon spring 210 but has a slightly different shape

in that it is disposed within a cavity 252 behind a removable cradle 254. As will be apparent, the spring 250 urges the cradle 254 outwardly along axis 226. Inasmuch as the spring 250 extends more than about 90 degrees, it also allows force vectors near ends 256 and 258, which, in the embodiment depicted, are also attachment points for the spring 250.

Figure 12 is a block diagram of one preferred apparatus of the invention. Referring to Figure 12, it will be seen that gas (not shown) is preferably passed via gas line 310 to gas booster 312 in which it is compressed to pressure required by micro turbine generator 314. In general, the gas must be compressed to a pressure in excess of 30 p.s.i.g., although pressures as low as about 20 p.s.i.g. and as high as 360 p.s.i.g. or more also may be used.

In Figures 12 and 13, a micro turbine generator 314 is shown as the preferred receiver of the gas via line 313. In other embodiments, not shown, a larger gas turbine and/or a fuel cell may be substituted for the micro turbine generator 314.

In one embodiment, in addition to increasing the pressure of the natural gas, the gas booster 312 also generally increases its temperature to a temperature within the range of from about 100 to about 150 degrees Fahrenheit. In one embodiment, the gas booster 312 increases the temperature of the natural gas from pipeline temperature to a temperature of from about 100 to about 120 degrees Fahrenheit.

The compressed gas from gas booster 312 is then fed via line 313 to micro turbine generator 314. The components used in gas booster 312 and in micro turbine generator 314 will now be described.

Figure 13 is a schematic diagram of the gas booster system 312 of Figure 12. Referring to Figure 12, it will be seen that gas booster system 312 preferably is comprised of a guided rotor compressor 316.

The guided rotor compressor 316 depicted in Figure 13 is substantially identical to the guided rotor compressor 10 disclosed in United States patent 5,431,551, the entire disclosure of which is hereby incorporated by reference into this patent application. This guided rotor compressor is preferably comprised of a housing comprising a curved inner surface with a profile equidistant from a trochoidal curve, an eccentric mounted on a shaft disposed within said housing, a first rotor mounted on said eccentric shaft which is comprised of a first side, a second side, and a third side, a first partial bore disposed at the intersection of said first side and said second side, a second partial bore disposed at the intersection of said second side and said third side, a third partial bore disposed at the intersection of said third side and said first side, a first solid roller disposed and rotatably mounted within said first partial bore, a second solid roller disposed and rotatably mounted within said second partial bore, and a third solid roller disposed and rotatably mounted within said third partial bore.

The rotor is comprised of a front face, a back face, said first side, said second side, and said third side. A first opening is formed between and communicates between said front face and said first side, a second opening is formed between and communicates between said back face and said first side, wherein each of said first opening and said second opening is substantially equidistant and symmetrical between said first partial bore and said second partial bore. A third opening is formed between and communicates between said front face and said second side. A fourth opening is

formed between and communicates between said back face and said second side, wherein each of said third opening and said fourth opening is substantially equidistant and symmetrical between said second partial bore and said third partial bore. A fifth opening is formed between and communicates between said front face and said third side. A sixth opening is formed between and communicates between said back face and said third side, wherein each of said fifth opening and said sixth opening is substantially equidistant and symmetrical between said third partial bore and said first partial bore.

Each of said first partial bore, said second partial bore, and said third partial bore is comprised of a centerpoint which, as said rotary device rotates, moves along said trochoidal curve.

Each of said first opening, said second opening, said third opening, said fourth opening, said fifth opening, and said sixth opening has a substantially U-shaped cross-sectional shape defined by a first linear side, a second linear side, and an arcuate section joining said first linear side and said second linear side. The first linear side and the second linear side are disposed with respect to each other at an angle of less than ninety degrees; and said substantially U-shaped cross-sectional shape has a depth which is at least equal to its width.

The diameter of said first roller is equal to the diameter of said second solid roller, and the diameter of said second solid roller is equal to the diameter of said third solid roller.

The widths of each of said first opening, said second opening, said third opening, said fourth opening, said fifth opening, and said sixth opening are substantially the same, and the width of each of said openings is less than the diameter of said first solid roller.

Each of said first side, said second side, and said third side has substantially the same geometry and size and is a composite shape comprised of a first section and a second section, wherein said first section has a shape which is different from that of said second section.

The aforementioned compressor is a very preferred embodiment of the rotary positive displacement compressor which may be used as compressor 316; it is substantially smaller, more reliable, more durable, and quieter than prior art compressors. However, one may use other rotary positive displacement compressors such as, e.g., one or more of the compressors described in United States patents 5,605,124, 5,597,287, 5,537,974, 5,522,356, 5,489,199, 5,459,358, 5,410,998, 5,063,750, 4,531,899, and the like. The entire disclosure of each of these United States patents is hereby incorporated by reference into this specification.

Referring again to figure 13, it will be seen that the compressed gas from compressor 316 is fed via line 313 to micro turbine generator 314. As is disclosed in United States patent 5,810,524 (see, e.g., claim 1 thereof), such micro turbine generator 314 is a turbogenerator set including a turbogenerator power controller, wherein said turbogenerator also includes a compressor, a turbine, a combustor with a plurality of gaseous fuel nozzles and a plurality of air inlets, and a permanent magnet motor generator; see, e.g., Figures 1 and 2 of such patent and the description associated with such Figures.

The assignee of United States patent 5,819,524 manufactures and sells micro turbine generators, such as those described in its patent.

Similar micro turbine generators 314 are also manufactured and sold by Elliott Energy Systems company of 2901 S.E. Monroe Street, Stuart, Florida 34997 as “The TA Series Turbo Alternator.”

Such micro turbines are also manufactured by the Northern Research and Engineering Corporation (NREC), of Boston, Mass., which is a wholly-owned subsidiary of Ingersoll-Rand Company; see, e.g., page 64 of the June, 1998 issue of “Diesel & Gas Turbine Worldwide.” These micro turbines are adapted to be used with either generators (to produce micro turbine generators) or, alternatively, without such generators in mechanical drive applications. It will be apparent to those skilled in the art that applicants’ rotary positive displacement device may be used with either of these applications.

In general, and as is known to those skilled in the art, the micro turbine generator 314 is comprised of a radial, mixed flow or axial, turbine and compressor and a generator rotor and stator. The system also contains a combustor, bearings and bearings lubrication system. The micro turbine generator 314 operates on a Brayton cycle of the open type; see, e.g., page 48 of the June, 1998 issue of “Diesel & Gas Turbine Worldwide.”

Referring again to Figure 13, and in the preferred embodiment depicted therein, it will be seen that natural gas is fed via line 310 to manual ball valve 318 and thence to Y-strainer 320, which removes any heavy, solid particles entrained within the gas stream. The gas is then passed to check valve 322, which prevents backflow of the natural gas. Relief valve 324 prevents overpressurization of the system.

The natural gas is then fed via line 326 to the compressor 316, which is described elsewhere in this specification in detail. Referring to Figure 13, it will be seen that compressor 316 is operatively connected via distance piece 328, housing a coupling (not shown) which connects the shafts (not shown) of compressor 316 and electric motor 330. The compressor 316, distance piece 328, and electric motor 330 are mounted on or near a receiving tank, which receives and separates a substantial portion of the oil used in compressor 316.

Referring again to Figure 13, when the compressor 316 has compressed a portion of natural gas, such natural gas also contains some oil. The gas/oil mixture is then fed via line 334 to check valve 336 (which prevents backflow), and thence to relief valve 338 (which prevents overpressurization), and then via line 340 to radiator/heat exchanger 342.

Referring again to Figure 13, it will be seen that oil is charged into the system via line 344 through plug 346. Any conventional oil or lubricating fluid may be used; in one embodiment, automatic transmission fluid sold as “ATF” by automotive supply houses is used. Alternatively, or additionally, one may utilize commercially available antifreeze components, such as, e.g., ethylene glycol, mixtures of ethylene glycol and water, etc. Alternatively, or additionally, one may utilize the liquid phase of the gas being compressed.

A portion of the oil which was introduced via line 344 resides in the bottom of tank 332. This portion of the oil is pressurized by the natural gas in the tank, and the pressurized oil is then pushed by pressurized gas through line 348, through check valve (to eliminate back flow), and then past needle valve 352, into radiator 354; a similar needle valve 352 may be used after the radiator 354. The oil flowing into radiator 354 is

then cooled to a temperature which generally is from about 10 to about 30 degrees Fahrenheit above the ambient air temperature. The cooled oil then exits radiator 354 via line 356, passes through oil filter 358, and then is returned to compressor 316 where it is injected; the injection is controlled by solenoid valve 360.

In the preferred embodiment depicted in Figure 13, a fan 362 is shown as the cooling means; this fan is preferably driven by motor 364; in the preferred embodiment depicted in Figure 13, air is drawn through radiators 342 and 354 in the direction of arrows 363. As will be apparent to those skilled in the art, other cooling means (such as water cooling) also and/or alternatively may be used.

Referring again to Figure 13, the cooled oil and gas mixture from radiator 342 is passed via line 366 through ball valve 368 and then introduced into tank 332 at point 370.

In the operation of the system depicted in Figure 13, a sight gauge 380 provides visual indication of how much oil is in receiving tank 332. When an excess of such oil is present, it may be drained via manual valve 384. In general, it is preferred to have from about 20 to about 30 volume percent of the tank be comprised of oil.

Referring again to Figure 13, compressed gas may be delivered to turbogenerator 314 through port 386, which is preferably located on receiving tank 332 but above the oil level (not shown) in such tank. Bypass line 388 and pressure relief valve 390 allows excess gas flow to be diverted back into inlet line 326. That gas which is not in bypass line 388 flows via line 313 through check valve 392 (to prevent backflow), manual valve 394 and thence to turbogenerator 314.

Thus, and again referring to Figure 13, it will be seen that, in this preferred embodiment, there is a turbo alternator 314, an oil lubricated rotary displacement

compressor 316, a receiving tank 332, a means 310 for feeding gas to the rotary positive displacement compressor, a means 346 for feeding oil to the receiving tank, a means 342 for cooling a mixture of gas and oil, a means 332 for separating a mixture of gas and oil, and a means 356 for feeding oil to the rotary positive displacement compressor.

In the preferred embodiment depicted in Figure 13, there are two separate means for controlling the flow capacity of compressor 316. One such means, discussed elsewhere in this specification as a bypass loop, is the combination of port 386, line 388, relief valve 390, and line 391. Another such means is to control the inlet flow of the natural gas by means of control valve 396. As will be apparent, both such means, singly or in combination, exert their control in response to the gas needs of turbogenerator 314.

Figure 14 is a schematic representation of a hybrid booster system 420 which is comprised of a rotary positive displacement device assembly 422 operatively connected via line 424 to a reciprocating compressor 426.

Rotary positive displacement device assembly 422 may be comprised of one or more of the rotary positive displacement devices depicted in either Figures 1-8 (with solid rollers) and/or 9-11 (hollow rollers). Alternatively, or additionally, the displacement device 422 may be comprised of one or more of the rotary compressors claimed in United States patent 5,769,619, the entire disclosure of which is hereby incorporated by reference into this specification.

United States patent 5,769,619 claims a rotary device comprised of a housing comprising a curved inner surface in the shape of a trochoid and an interior wall, an eccentric mounted on a shaft disposed within said housing, a first rotor mounted on said eccentric shaft which is comprised of a first side and a second side, a first pin attached to

said rotor and extending from said rotor to said interior wall of said housing, and a second pin attached to said rotor and extending from said rotor to said interior wall of said housing, and a third pin attached to said rotor and extending from said rotor to said interior wall of said housing. A continuously arcuate track is disposed within said interior wall of said housing, wherein said continuously arcuate track is in the shape of an involuted trochoid. Each of said first pin, said second pin, and said third pin has a distal end which is disposed within said continuously arcuate track. Each of said first pin, said second pin, and said third pin has a distal end comprised of a shaft disposed within a rotatable sleeve. The rotor is comprised of a multiplicity of apices, wherein each such apex forms a compliant seal with said curved inner surface, and wherein each said apex is comprised of a separate curved surface which is formed from a strip of material pressed into a recess. The curved inner surface of the housing is generated from an ideal epitrochoidal curve and is outwardly recessed from said ideal epitrochoidal curve by a distance of from about 0.05 to about 5 times as great as the eccentricity of said eccentric. The diameter of the distal end of each of said first pin and said second pin is from about 2 to about 4 times as great as the eccentricity of the eccentric. Each of the first pin, the second pin, and the third pin extends from beyond the interior wall of the housing by from about 2 to about 2 times the diameter of each of said pins.

Referring again to Figure 14, it is preferred that several rotary positive displacement devices 10 and 10' be used to compress the gas ultimately fed via line 424 to reciprocating positive compressor 426. As is disclosed in United States patent 5,431,551, the devices 10 and 10' are staged to provide a multiplicity of fluid compression means in series.

Thus, as was disclosed in United States patent 5,431,551 (see lines 62 et seq. of column 9), “In one embodiment, not shown, a series of four rotors are used to compress natural gas. The first two stacked rotors are substantially identical and relatively large; they are 180 degrees out of phase with each other; and they are used to compress natural gas to an intermediate pressure level of from about 150 to about 200 p.s.i.g. The third stacked rotor, which comprises the second stage of the device, is substantially smaller than the first two and compresses the natural gas to a higher pressure of from about 800 to about 1,000 p.s.i.g. The last stacked compressor, which is yet smaller, is the third stage of the device and compresses the natural gas to a pressure of from about 3,600 to about 4,500 p.s.i.g.”

Many other staged compressor circuits will be apparent to those skilled in the art. What is common to all of them, however, is the presence of at least one rotary positive displacement device 10 whose output is directly or indirectly operatively connected to at least one cylinder of a reciprocating positive displacement compressor 426.

One may use any of the reciprocating positive displacement compressor designs well known to the art. Thus, by way of illustration and not limitation, one may use one or more of the reciprocating positive compressor designs disclosed in United States patents 5,811,669, 5,457,964, 5,411,054, 5,311,902, 4,345,880, 4,332,144, 3,965,253, 3,719,749, 3,656,905, 3,585,451, and the like. The entire disclosure of each of these United States patents is hereby incorporated by reference into this specification.

Referring again to Figure 14, it will be apparent that reciprocating positive displacement compressor 426 may be comprised of one or more stages. In the preferred embodiment depicted, compressor 426 is comprised of stages 428 and 430.

Referring again to Figure 14, an electric motor 432 connected by shafts 434 and 436 is operatively connected to compressors 428/430 and 10/10'. It will be apparent that many other such drive assemblies may be used.

In one embodiment, not shown, the gas from one stage of either the 10/10' assembly and/or the 428/430 assembly is cooled prior to the time it is passed to the next stage. In this embodiment, it is preferred to cool the gas exiting each stage at least about 10 degrees Fahrenheit prior to the time it is introduced to the next compressor stage.

Figure 15 depicts an assembly 450 similar to the assembly 420 depicted in Figure 14. Referring to Figure 15, it will be seen that gas is fed to compressor assembly 10/10' by line 452. In this embodiment, some pressurized gas at an intermediate pressure is fed from compressor 10 via line 454 to turbine or micro-turbine or fuel cell 456. Alternatively, or additionally, gas is fed to electrical generation assembly 456 by a separate compressor (not shown).

The electrical output from electrical generation assembly 456 is used, at least in part, to power electrical motor 432. Additionally, electrical power is fed via lines 458 and/or 460 to an electrical vehicle recharging station 462 and/or to an electrical load 464.

Referring again to Figure 15, and in the preferred embodiment depicted therein, waste heat produced in turbine/microturbine/fuel cell 456 is fed via line 466 to a heat load 468, where the heat can be advantageously utilized, such as, e.g., heating means, cooling means, industrial processes, etc. Additionally, the high pressure discharge from compressor 430 is fed via line 470 to a compressed natural gas refueling system 472.

In one embodiment, not shown, guided rotor assembly 10/10' is replaced is conventional compressor means such as reciprocating compressor, or other positive

displacement compressor. Alternatively, or additionally, the reciprocating compressor assembly may be replaced by one or more rotary positive displacement devices which, preferably, are adapted to produce a more highly pressurized gas output the either compressor 10 or compressor 10'. Such an arrangement is illustrated in Figure 16, wherein rotary positive displacement devices 11/11' are are higher pressure compressors used. In one embodiment, not shown, separate electrical motors are used to power one or more different compressors.

Figure 17 is a schematic representation of an assembly 500 in which electrical generation assembly 456 is used to power a motor 502 which in turn provides power to rotary positive displacement device 504. Gas from well head 506 is passed via line 508, and pressurized gas from rotary positive displacement device 504 is fed via line 510 to electrical generation assembly 456, wherein it is converted to electrical energy. Some of this energy is fed via line 512 to electric motor 432, which provides motive power to a single or multi-compressor guided rotary compressor 514; this "well head booster" may be similar in design to the compressor assembly illustrated in Figures 1-8, or to the compressor assembly illustrated in Figures 9-12, and it may contain one more compressor stages. The output from rotary positive displacement assembly 514 may be sent via line 516 to gas processing and/or gas transmission lines. The input to rotary positive displacement assembly 514 may come from well head 518, which may be (but need not be) the same well head as well head 516, via line 520.

Figure 18 is a sectional view of a multistage rotor assembly 600 which is comprised of a shaft 602 integrally connected to eccentric 604 and eccentric 606. The rotating shaft 600/eccentric 604/eccentric 606/ assembly is supported by main bearings

608 and 610; eccentrics 604 and 606 are disposed within bearings 612 and 614; and the eccentrics 604/606 and bearings 612/614 assemblies are disposed within guided rotors 616 and 618. This arrangement is somewhat similar to that depicted in Figure 1, wherein eccentric 52 is disposed within guided rotor 60.

As will be apparent to those skilled in the art, one shaft 602 is being used to translate two rotors 616 and 618. The gas to be compressed is introduced into port 620 and then introduced into the volume created by the rotor 616 and the housing 622. The compressed gas from the volume created by the rotor 616 and the housing 622 is then introduced within an annulus 624 within intermediate plate 626 via port 628 and then sent into the volume created by rotor 618 and housing 630 through port 632. After being further compressed in this second rotor system, it is then sent to discharge annulus 632 within discharge housing 634 by port 636.

Referring to Figure 1, it will be seen that guided rotor assembly 10 has a housing 12 with a thickness 640 which is slightly larger than the thickness of the rotor 16 disposed within such housing (see Figure 1). Similarly, the thickness 642 of rotor assembly 616, and the thickness 644 of rotor assembly 618 are also slightly smaller than the thicknesses of the housings in which the guided rotors are disposed.

It is preferred that the thickness 644 be less than the thickness 642. In one embodiment, thickness 642 is at least 1.1 times as great as the thickness 644 and, preferably, at least 1.5 times as great as the thickness 644.

It will be apparent that, with the assembly 600 of Figure 18, one can achieve higher pressures with lower operating costs.

Figure 19 illustrates an guided rotor assembly 670 comprised of a multiplicity of guided rotors 672 and 674. Shaft 676 is rotated by electric motor 678 which, in the embodiment depicted, is comprised of motor shaft 680, motor rotor 682, and stator 684 supported by bearings 686 and 688. The motor shaft 680 is directly coupled to compressor shaft 676 by means a coupling 690.

The compressor shaft 676 rotates one or more of rotors 672 and 674, which may be of the same size, a different size, of the same function, and/or of a different function.

The motor 678 is cooled by incoming gas (not shown), and such incoming gas is then passed to compressor 692, wherein it is distributed equally to the rotor assemblies 672 and 674, which are disposed within housings 694 and 696, respectively.

In the embodiment depicted in Figure 19, the rotor assemblies 674 and 676 have substantially the same geometry and capacity. In another embodiment, not shown, the rotor assemblies 674 and 674 have different geometries and/or capacities.

Referring again to Figure 19, it will be seen that the entire compressor and drive assembly is disposed within hermetic enclosure 698. The end flange 700 forms an interface 702 with enclosure 698 which is a hermetic seal.

Figure 20 is a schematic diagram of a compressor system 750 comprising guided rotor compressor 514 operatively connected an electric motor or other motive means (not shown), a liquid separator 752 operatively connected to compressor 514 by line 754, an optional cooler 756 operatively connected to liquid separator 752 by line 758, a optional water separator 760 operatively connected to cooler 756 by line 762, a second cooler 764 operatively connected to separator 752 by line 766, an oil filter 768 operatively connected to second cooler 764 by line 770, a control valve 772, and a liquid feed line 774.

In the process depicted in Figure 20, gas is fed to compressor 514 via line 776. The gas fed via line 776 may be pure gas, a mixture of gas and water, and mixture of gas and oil, and mixture of gas, water, and oil, etc.

The gas fed via line 776, even when it is not pure, generally contains at least about 95 volume percent of material in the gaseous phase. Such gas generally is at a pressure of from about ambient pressure to about 3,000 pounds per square inch gauge. The gas preferably is a hydrocarbon gas.

The gas fed via line 776 is compressed in compressor 514 to a pressure of from about 5 pounds per square inch gauge to about 6,000 pounds per square inch gauge, or more. As will be apparent to those skilled in the art, the gas mixture compressed in compressor 514 has a dew point which is higher than the dew point of the inlet gas mixture; and, thus, the impurities which are in the vapor state in the inlet gas mixture tend to condense and liquefy.

In one embodiment, not shown, the outlet gas mixture is maintained at a temperature that is higher than the dew point of the vapor impurities in the inlet gas mixture. Thus, in one embodiment, the outlet gas mixture is maintained at a temperature of at least about 100 degrees Fahrenheit and, more preferably, at least about 160 degrees Fahrenheit.

Referring again to Figure 20, the separator 752 separates the liquid in the output stream, such as liquid oil, from the gaseous stream; however, the water in the output stream is generally maintained at a higher temperature and, thus, is not separated from the gas by the separator 752.

One may use any of the conventional separators adapted for the purpose of separating the lubricating liquid from the gaseous stream. Thus, by way of illustration and not limitation, one may use an expansion tank with wire mesh, a cyclone separator, a baffled separator, a cooler, and the like. Thus, e.g., one may use one or more of the oil/water separators described in United States patents 5,6286,748 (liquid separator), 5,296,150 (water/oil separator), 4,175,040 (centrifugal water/oil separator), 3,923,480 (oil separator), 5,565,101 (oil and water separator), 4,915,823 (assembly for separation of oil from water), and the like. The entire disclosure of each of these United States patents is hereby incorporated by reference into this specification.

The lubricating liquid so separated, such as oil, is then fed by line 766 to lubricating liquid cooler 764. One may use any of the liquid coolers adapted for this purpose; and one may use gaseous or liquid cooling fluids. Thus, e.g., one may use one or more of the devices and/or processes described in United States patents 5,056,601 (air compressor cooling system), 5,087,108 (oil flooded screw compressor), 4,968,223 (gas and oil cooling system for hermetic compressor), 4,431,390 (condensate control apparatus for oil flooded compressor), 5,088,299 (industrial liquid circulating and cooling machine) and the like. The entire disclosure of each of these United States patents is hereby incorporated by reference into this specification.

Referring again to Figure 20, the cooled lubricating fluid from cooler 764 is passed via line 770 to a lubricating fluid filter 768, such as, e.g., an oil filter. One may use any suitable filter such as, e.g., a canister oil filter, a cartridge oil filter, etc.

The filtered lubricating fluid is then passed via line 774 through control valve 772 and back into fluid-lubricated compressor 514.

Referring again to Figure 20, the gas separated in separator 752 is optionally passed via line 758 to cooler 756, in which any water entrained in the gas is removed from the gaseous phase. As will be apparent to those skilled in the art, when the gas/water mixture is cooled, its dew point is reached, causes condensation and removal of the water from the gaseous phase. One may use any of the gas coolers known to those skilled in the art. Thus, e.g., one may use a conventional heat exchanger.

The output from cooler 756 contains gas (in a gaseous) and water (in a liquid phase). This mixture is then fed to separator 760, which separates these two phases. One may use any of the separators adapted for this purpose. Thus, e.g., one may use a separator similar to the one used as separator 752.

The dry gas from separator 760 is fed via line 780 to storage or use (not shown). The liquid water and other impurities (as, e.g., heavy hydrocarbons) is fed via line 782 to disposal (not shown).

The system 750, described in Figure 20, is especially adapted for the situation where the lubricating fluid is lubricating oil or the liquid phase of the gas being compressed. The system 800, described in Figure 21, is especially adapted for the situation where the lubricating fluid is either glycol or a glycol/water mixture. .

The system 800 is similar to the system 750 but differs therefrom in certain respects. In the first place, the glycol via line 753 contains a substantial amount of water absorbed in it. In the second place, the separator separates the liquid glycol/water mixture (in the liquid phase) from the gas (in the gaseous phase).

In the preferred embodiment depicted in Figure 21, the gas exiting separator 752 is substantially dry. However, to insure an even higher degree of dryness, one may pass

this gas via line 758 to cooler 756 and then to separator 760, which will, under the appropriate conditions, will further purify the gas. The purified gas then may be passed via line 780 to use and/or storage.

Referring again to Figure 21, one may remove water from the glycol/water mixture produced in separator 752 in glycol dehydrator 786. One may use one or more of the glycol dehydrators known to those skilled in the art. Reference may be had, e.g., to United States patents 5,350,519 (glycol dehydrator), 5,346,537 (glycol dehydrator), 5,209,762 (glycol dehydrator), 5,167,675 (regenerator for glycol dehydrator), 5,084,074 (method and apparatus for separating and regenerating water or light aromatic hydrocarbons from gaseous streams) and the like. The entire disclosure of each of these United States patents is hereby incorporated by reference into this specification.

The glycol dehydrator 786, by removing water from the glycol, increases its temperature to some degree. In one embodiment, depicted in Figure 21, a portion of the the glycol/water mixture is cooled and then returned to the compressor in order to lubricate, seal, and cool the compression process. Thus, referring to Figure 21, some or all of the glycol/water mixture is fed via line 766 to cooler 764, which may, e.g., be a heat exchanger. The cooled glycol/water mixture is then fed via line 770 to filter 768, which will remove oil and other impurities from the glycol/water mixture. The purified glycol/water mixture is then passed, as required, through valve 772 and back into compressor 514 via line 788.

As will be apparent to those skilled in the art, one may balance the streams fed via lines 790 and 788 to achieve equilibrium for cooling and water removal. One may use, e.g., control valve 792 operatively connected to a controller (not shown).

Referring again to Figure 21, and in the preferred embodiment depicted therein, dehydrated glycol from dehydrator 786 may be either be pumped via pump 796 to inlet line 776 (via line 794) or, when the back pressure from the compressor discharge 514 is substantial enough, will be forced without a pump into compressor 514.

In one embodiment, not shown, a cooler 764 is disposed between dehydrator 786 and compressor 514 to further cool the recycled glycol. The water from the dehydration process may be fed via line 798 to disposal.

Figure 22 is a gas booster system 1000 that is similar to the system 750 depicted in Figure 20 but differs therefrom in that it takes gas from a wellhead (not shown) or a petroleum storage facility (not shown) via line 776; in the embodiment depicted in Figure 22, the heat exchanger 756 is disposed between the compressor 514 and the separator 760. The gas is then compressed by guided rotor compressor 514 which, in the embodiment depicted, is preferably driven by a driver 516 that may be, e.g., a combustion engine 516, an electric motor 516, etc. In one aspect of this embodiment, the driver is an internal combustion engine fueled by natural gas, or diesel oil, or gasoline. This type of internal combustion engines are well known. Reference may be had to the Caterpillar internal combustion engine model 3306.

Referring again to Figure 22, the compressed gas produced in compressor 514 generally is at a pressure of from about 2 to about 10,000 pounds per square inch and, preferably, at a pressure of from about 50 to 1,100 pounds per square inch. The compressed gas is fed by line 754 to a thermostatic control valve 755 that bypasses cooler 756 when the temperature of the compressed gas is relatively low, i.e., less than about 120 degrees Fahrenheit in one embodiment. When the temperature of the compressed gas

exceeds the specified temperature, the compressed gas is directed via line 758 to cooler 756 wherein it is first cooled and then directed to a separator 760 via line 762. In the separator 760, liquid is separated from the gas; the liquids so separated may include water, oil (a primary constituent). The dehydrated gas is then fed through output port 780. The liquids are preferably fed via line 770 to a liquid filter 768 and thence via line 774 to control valve 772, which allows one to meter the amount of liquid, if any, that is returned to the compressor 514. It is preferred to return at least some oil, as a lubricant, to the compressor 514.

One may use any of the thermostatic control valves that are commercially available. Thus, e.g., by way of illustration and not limitation, one may use "Thermostatic Control Valve," part # A110-080, sold by the Fluid Power Energy company of Waukesha, Wisconsin.

Figure 23 describes an assembly that is similar in some respects to the assembly of Figure 21 but differs therefrom in that the second separator 760 is comprised of a drain line 791 that feeds the separated liquid through a check valve 793 (to prevent backflow) and thence to and through a fluid pump 797. The pumped liquid from pump 797 is preferably passed through a control valve 799 and then fed into first separator 752. In one preferred aspect of this embodiment, waste from separator 860 is fed via line 782 to a control valve 801.

Figure 24 describes an assembly that is similar in some respects to the assembly of Figure 21 but differs therefrom by a cooler 756 being disposed between the compressor 514 and the first separator 752, thereby allowing one to dispense with the use of the second separator 760 (see Figure 21). In the embodiment of Figure 24, for

simplicity of representation, unnecessary detail (such as, e.g., a driver 516) has been omitted.

It is to be understood that the aforementioned description is illustrative only and that changes can be made in the apparatus, in the ingredients and their proportions, and in the sequence of combinations and process steps, as well as in other aspects of the invention discussed herein, without departing from the scope of the invention as defined in the following claims.